

Stable Field Emitters Using Inverse Opal Structures

Completed Technology Project (2016 - 2018)

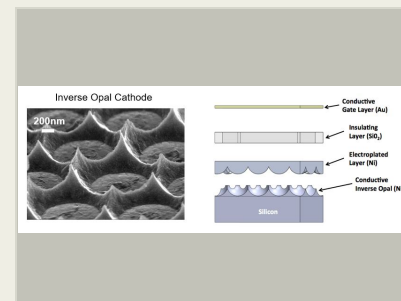


Project Introduction

For the first time since they have been used in photonics applications, Inverse Opal structures are being applied to field emission applications. JPL-pioneered Carbon Nanotubes (CNTs) bundle arrays are ideal for field emission devices due to their sharp tips, however their stochastic microstructure leads to deformation at low applied mechanical/electrical loads and frequent failure when used as vacuum microelectronic devices. Inverse opal structures offer the salient geometric and field emission features of CNTs, but with greater control of array height and uniformity. Our objective is to create inverse opal field emission devices with enhanced reliability and robustness compared to CNT devices, while preserving desirable performance properties and reducing packaging challenges for sustaining harsh Venus/Jovian-like environments.

There is a need for alternate cold cathode materials that are as efficient, robust, and poor-vacuum tolerant as CNTs, but with improved rigidity to enable high-reliability, close-gap ($<5\mu\text{m}$) electrode integration for low voltage operation. Inverse opal structures offer many of the desired geometric/electronic features for field emission applications, such as sharp tips ($\sim 10\text{ nm}$) and high aspect ratios (25); they also offer more uniform array height, similar to Spindt-type cathodes [Spindt, C., et.al., J. Appl. Phys. (1976)], and are decidedly more robust than CNTs. Inverse opals can be fabricated using any conductive material, which allows for optimization of both field emission and structural properties. While significant advances are being made in solid-state devices involving SiC, SiGe, and SoI (silicon on insulator), which enjoy higher maturity and integration levels, challenges concerning failing Ohmic contacts, and the existence of finite dark current make them unsuitable for certain niche field emission applications. Vacuum microelectronics with field emission cathodes, when developed using an innovative planar vacuum packaging technology, can become the desired technology to fill this need. This development will lead to structurally robust and reliable miniaturized field emitting devices capable of sustaining harsh Venus or Jovian-like environments. This is the first time inverse opal structures are being applied for field emission devices/sensors, and can lead to a new class of devices for NASA-JPL.

The objective is to create inverse opal field emission vacuum electronics devices with enhanced reliability and structural robustness compared to CNT devices while preserving desirable properties, such as low threshold operation and robustness to poor vacuums. Inverse opals can be used to create an ordered 2D array of conducting sharp tips suitable for high temperature applications. These can provide emission at low threshold fields while also offering a rigid structure that does not deform under mechanical/electrical loads. The variation in inverse opal tip height is expected to be 2-3% ($\sim 100\text{s}$ of nm). The high reliability in tip height means the gap between components can be $<5\mu\text{m}$, resulting in low threshold operation and lower likelihood of device shorting/failure. This work aims to produce triode assemblies using semi-monolithic fabrication processes to achieve: 1) operating voltages of <10



Nickel Inverse Opal and integrated gate/cathode concept.

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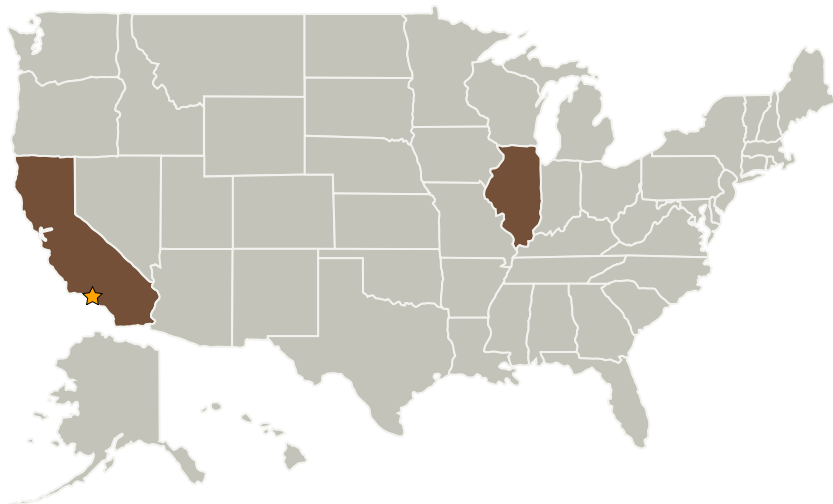


V on gate electrodes and <50 V on anodes, 2) transconductance of >1 μ Siemens, and 3) gains of ~ 10 at the end of year 2. Additionally, the triode assembly will be tested in a vacuum chamber up to 300 C (or higher depending on equipment availability).

Anticipated Benefits

This technology aligns itself with NASA's priorities to develop Extreme Environment electronics technologies for prolonged landed missions to Venus, Europa, and Titan. This proposed technology addresses the need for 500C-withstanding analog electronics, such as pre-amplifiers, and digital electronics, such as data recorders, for in-situ measurements including seismology and mineralogy.

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
★ Jet Propulsion Laboratory (JPL)	Lead Organization	NASA Center	Pasadena, California

Primary U.S. Work Locations

California	Illinois
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Organizational Responsibility

Responsible Mission Directorate:

Mission Support Directorate (MSD)

Lead Center / Facility:

Jet Propulsion Laboratory (JPL)

Responsible Program:

Center Independent Research & Development: JPL IRAD

Project Management

Program Manager:

Fred Y Hadaegh

Project Manager:

Fred Y Hadaegh

Principal Investigator:

Lauren C Montemayor

Co-Investigators:

Paul Braun

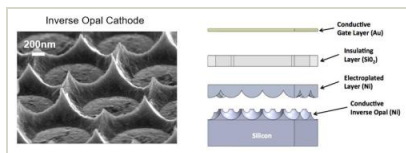
Harish M Manohara

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Images



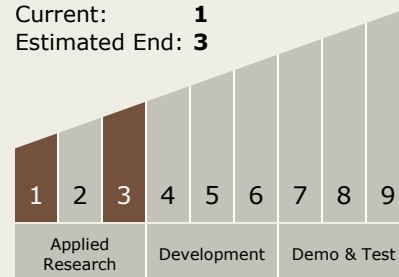
JPL_IRAD_Activities Project Image

Nickel Inverse Opal and integrated gate/cathode concept.

(<https://techport.nasa.gov/image/27900>)

Technology Maturity (TRL)

Start: **1**
Current: **1**
Estimated End: **3**



Technology Areas

Primary:

- TX12 Materials, Structures, Mechanical Systems, and Manufacturing
 - └ TX12.1 Materials
 - └ TX12.1.6 Materials for Electrical Power Generation, Energy Storage, Power Distribution and Electrical Machines

Target Destinations

Others Inside the Solar System, Foundational Knowledge

Supported Mission

Type

Push